BSM searches in multi-objects final states in ATLAS

Thijs Cornelissen[†]

Bergische Universität Wuppertal, Wuppertal, Germany

Recent results on searches for new physics from Run 1 of the Large Hadron Collider are reported. The ATLAS experiment has already collected more than 20 fb^{-1} of integrated luminosity, allowing for a large number of new phenomena searches in many different final states. No deviations from the Standard Model expectations are found, and corresponding constraints on physics beyond the Standard Model are obtained.

1. Introduction

The Standard Model (SM) of particle physics is regarded as a highly successful theory. It provides a description of matter and forces in our universe. The predictions made by the SM have been verified by many experiments to date and so far no discrepancies have been found. In particular the recent discovery of a Higgs-like boson fits very well in the SM framework. However the SM is not a complete theory as it leaves several questions unanswered, e.g. the nature of dark matter, and the origin of the light Higgs mass. There are many new theories that attempt to address these issues, which are collectively called 'physics beyond the SM' (BSM). In this contribution, some of the most important searches for new physics at the ATLAS experiment [1] are summarized. The references to the relevant theory papers can be found in the corresponding ATLAS publications.

2. Exotic Phenomena Searches

The exotic searches in ATLAS cover a wide range of signatures and models by looking at various final states. We provide the limits in a model independent way on the visible production cross-section of the new physics processes, and translate them into limits on the particle masses in various new physics models.

[†] On behalf of the ATLAS collaboration

2.1. Search for heavy resonances decaying into semi-leptonic $t\bar{t}$ pairs

In this search [2], two event topologies were tested. In highly boosted events, the decay products of the hadronically decaying top quark are expected to be collimated so that they all fall within a single 'fat' jet (R = 1.0). Such events should also contain one small jet (R = 0.4) close to the lepton, at least one small jet tagged as b-quark and sizable E_T^{miss}. Further acceptance is gained by considering in addition the resolved event topology, that consists of four small jets (or three small jets if one of them has mass greater than 60 GeV), one of which is tagged as originating from a b-quark, a lepton and sizable E_T^{miss}.

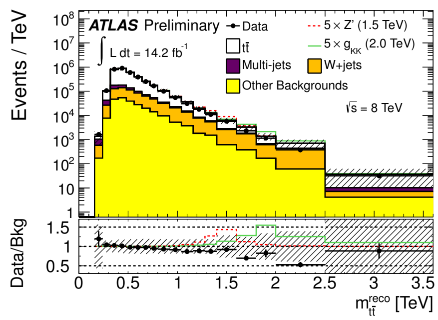

Fig. 1. The $t\bar{t}$ invariant mass spectrum, summing the spectra from the electron and muon channels and the two selection methods. The shaded areas indicate the total systematic uncertainties [2].

In both cases the invariant mass of the top pair is used as a discriminant (Fig. 1). In the boosted case, the longitudinal neutrino momentum p_z is obtained by imposing an on-shell mass of the leptonically decaying W boson candidate, whereas in the resolved case a χ^2 function is constructed to calculate the p_z and assign the jets to the top quarks. This search results in the exclusion of a leptophobic topcolor Z' boson [3] (assuming $\Gamma/m = 1.2\%$),

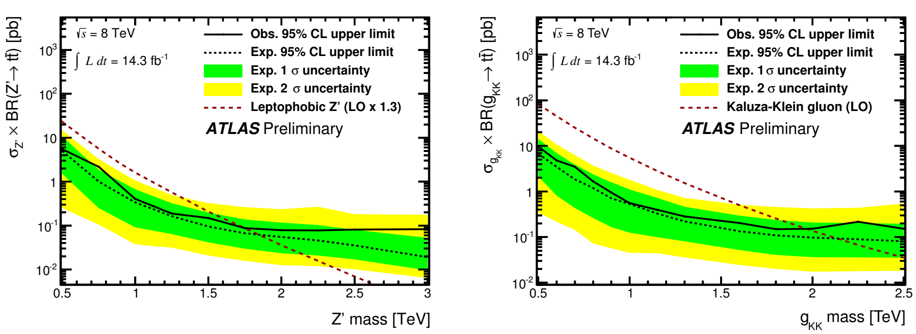

Fig. 2. Observed and expected upper cross section limits times the $t\bar{t}$ branching ratio on Z' bosons (left) and Kaluza-Klein gluons (right). The resolved and the boosted selections have been combined in the estimation of the limits. Both systematic and statistical uncertainties are included [2].

and a Kaluza-Klein gluon [4] (assuming $\Gamma/m = 15.3\%$), in the mass ranges 0.5 TeV $< m_{Z'} <$ 1.8 TeV and 0.5 TeV $< m_{g_{KK}} <$ 2.0 TeV (Fig. 2).

2.2. Search for vector-like quarks

Vector-like quarks are postulated by some models addressing the hierarchy problem, such as Little Higgs models and extra dimension models. The name refers to the feature that both chiralities transform in the same way under the weak symmetry group, which implies that they have no Yukawa coupling to the SM Higgs field.

The existence of the vector-like quarks would cause the cancellation of the quadratic divergences of the Higgs mass in the top loop. Vector-like quarks can appear with the SM charges (2/3, -1/3) or with exotic charges +5/3 and -4/3. They can form weak-isospin singlets, doublets and triplets. Pair production of these top partners is independent of their coupling to SM quarks.

The final states are expected to include third generation particles. The signatures investigated by ATLAS include $T \to Wb$ [5], $T \to Zt$ [6], $T \to Ht$ [7], and same-sign dileptons [8] (from the decay $T^+_{5/3} \to W^+t \to W^+W^+b$). The Ht analysis requires a lepton, at least six jets of which at least two are b-tagged, and missing transverse energy. The discriminant variable used is the total transverse energy $H_T = \sum_j p_T^j + p_T^l + E_T^{\rm miss}$, which is shown in Fig. 3. The combined limits on the masses of vector-like T quarks are shown in Fig. 4.

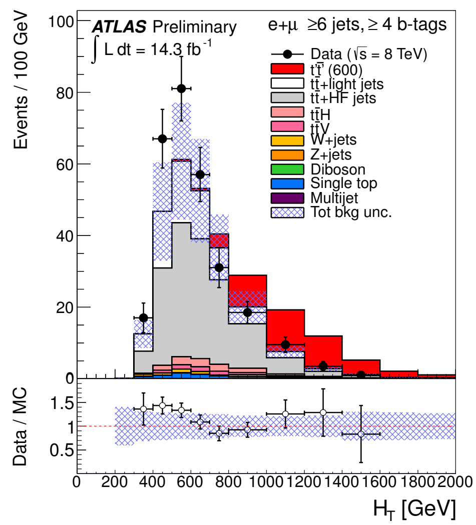

Fig. 3. Comparison between data and simulation for H_T in the combined e+jets and μ+jets channels with $\geq$ 6 jets and $\geq$ 4 b tags. Also shown is the expected $t'\bar{t}'$ signal corresponding to $m_{t'}$=600 GeV in the t' doublet scenario. The shaded area represents the total post-fit background uncertainty [7].

3. Supersymmetry Searches

Supersymmetry (SUSY) is one of the most favored theories for physics beyond the SM. The theory introduces new particles (sparticles) for each

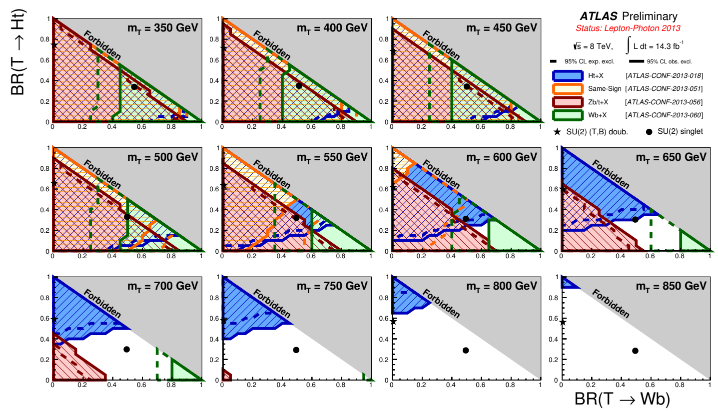

Fig. 4. Exclusion area in the branching ratio plane for individual signal mass point of vector-like T quarks [9].

SM particle that differ in spin by 1/2 from their SM counterparts. A new kind of symmetry called R-parity ($\mathrm{R} = (-1)^{3(B-L)+2S}$) is an important part of many SUSY models. In R-parity conserving (RPC) scenarios, the sparticles are produced in pairs and the lightest SUSY particle (LSP) is stable and weakly interacting. In a large variety of models the LSP is the lightest neutralino ($\tilde{\chi}_1^0$), which escapes detection in the detector and leads to missing transverse energy E_T^{miss}. In R-parity violating (RPV) models, the LSP is no longer stable and decays into SM particles. The analyses presented here are studied in the context of both RPC and RPV scenarios.

3.1. Search for gluino mediated stop/sbottom production

The mixing between the squark eigenstates may be large for the third generation, leading to masses for the stop and sbottom eigenstates that are much lighter than for the other squarks. As a consequence, stops and sbottoms could be produced with relatively large cross-sections at the LHC, either directly in pairs, or through $\tilde{g}\tilde{g}$ production followed by $\tilde{g} \to b\tilde{b}$ or $\tilde{g} \to t\tilde{t}$ decays. These models are probed by requiring zero or one lepton, at least three b-tagged jets, and missing energy [10]. The list of selection variables used includes the inclusive effective mass $m_{\mathrm{eff}}^{\mathrm{incl}}$, defined as the scalar sum of the E_T^{miss} and the p_T of all jets with $p_T > 30$ GeV. In the 1-lepton channel, the p_T of the leading lepton and the transverse mass $m_T = \sqrt{2p_T E_T^{\mathrm{miss}}(1 - \cos\Delta\phi(l, E_T^{\mathrm{miss}}))}$ are also used. Figure 5 shows the effective mass distributions as well as the limits on the $\tilde{\chi}_1^0$ and $\tilde{g}$ masses in the so-called *Gtt* model, where $\tilde{g} \to tt\tilde{\chi}_1^0$ via an off-shell stop.

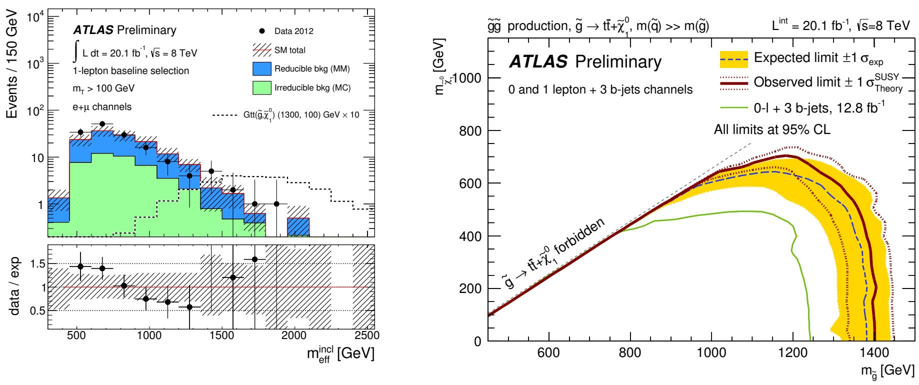

Fig. 5. (Left) The distribution of the inclusive effective mass for the baseline selection in the 1-lepton channel and after requiring $m_T > 100$ GeV, as observed in data together with the background prediction from the matrix method. The prediction for one signal point from the *Gtt* model is overlaid. (Right) Expected and observed exclusion limits in the $(m_{\tilde{g}}, m_{\tilde{\chi}_1^0})$ plane for the *Gtt* model [10].

3.2. Gluino pair production with many jets

The gluino pairs produced in RPC models may lead to cascade decays with many jets in the final state, e.g. $\tilde{g} \to \bar{q} + \tilde{q} \to \bar{q} + q' + \tilde{\chi}_1^{\pm} \to \bar{q} + q' + W + \tilde{\chi}_1^0$ (the 'gluino-squark model'). The search in Ref. [11] requires a large number (between 7 and 10) of jets, missing energy, as well as a veto against isolated leptons. Different signal regions are defined, e.g. requiring different number of b-tags, to provide sensitivity to models that predict either more or fewer b-jets than the SM background. A complementary set of signal regions clusters the 'standard' R=0.4 jets into large (R=1.0) composite jets, with cuts being placed on the scalar sum of masses of the composite jets. In all signal regions the final selection is $E_T^{\mathrm{miss}}/\sqrt{H_T} > 4$ GeV$^{1/2}$, where H_T is the scalar sum of transverse momenta of all jets with $p_T > 40$ GeV and $|\eta| < 2.8$. This selection variable has the property that its shape is approximately independent of the number of jets, thus the SM multijet background can be estimated from the lower jet multiplicity bins which are free of signal. Figure 6 shows the $E_T^{\mathrm{miss}}/\sqrt{H_T}$ distribution for one of the signal regions, as well as the combined limits on the $\tilde{\chi}_1^0$ and $\tilde{g}$ masses.

3.3. RPV decays with large jet multiplicities

In the context of RPV SUSY, both the gluino and neutralino can play the role of LSP. When they undergo decays with non-zero couplings of superfields of the type $\lambda''_{ijk} U_i D_j D_k$, the result would be 6-quark or 10-

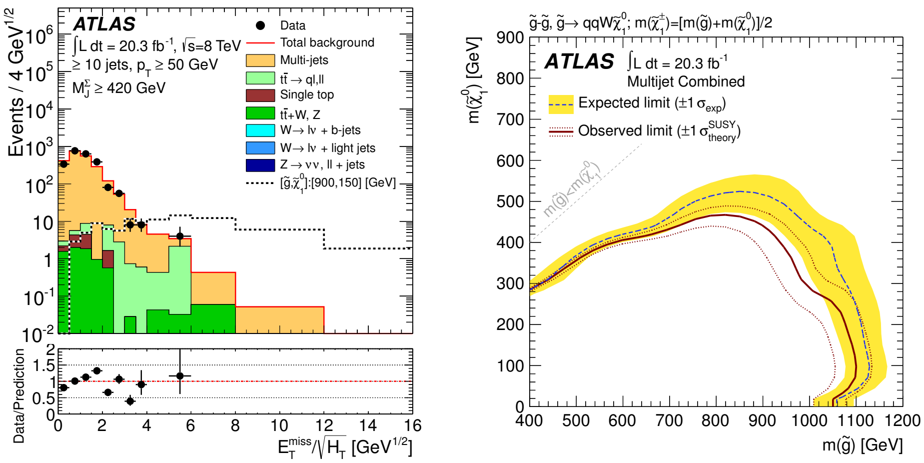

Fig. 6. (Left) $E_T^{\text{miss}}/\sqrt{H_T}$ distribution for the signal region requiring at least 10 jets, and a scalar sum of composite jet masses larger than 420 GeV. Also shown is the expected signal corresponding to $m_{\tilde{g}} = 900$ GeV and $m_{\tilde{\chi}_1^0} = 150$ GeV, with $\tilde{g} \to t+\bar{t}+\tilde{\chi}_1^0$. (Right) 95% CL exclusion curve for the simplified gluino-squark (via $\tilde{\chi}_1^\pm$) model, for fixed $x = 1/2$, where $x = (m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0})/(m_{\tilde{g}} - m_{\tilde{\chi}_1^0})$, and varying $\tilde{\chi}_1^0$ mass [11].

quark final states. Evidence of multijet events is probed by counting the number of high transverse momentum (at least 80 GeV) 6-jet and 7-jet events, with various b-tagging requirements added to enhance the sensitivity to couplings that favour decays to third generation quarks [12]. The number of jets, the p_T cut that is used to select jets, and the number of b-tags are optimised separately for each signal model taking into account experimental and theoretical uncertainties. The background yield in each of the signal regions is estimated by using a signal-depleted control region in data and then projecting into the signal region using a factor that is determined from multi-jet simulation. The distribution for one of the signal regions (6-jet) is shown in Fig. 7. No excess above SM background is seen and results are interpreted for all possible RPV branching fractions of gluino decays in the considered quark models. Figure 7 shows the obtained cross-section limits in one of the 6-quark models.

3.4. Search for long lived particles with displaced vertices

Several extensions to the SM posit the existence of heavy particles with lifetimes that can vary from picoseconds to nanoseconds. The decays of such particles form a unique signature of vertices that are displaced from the pp

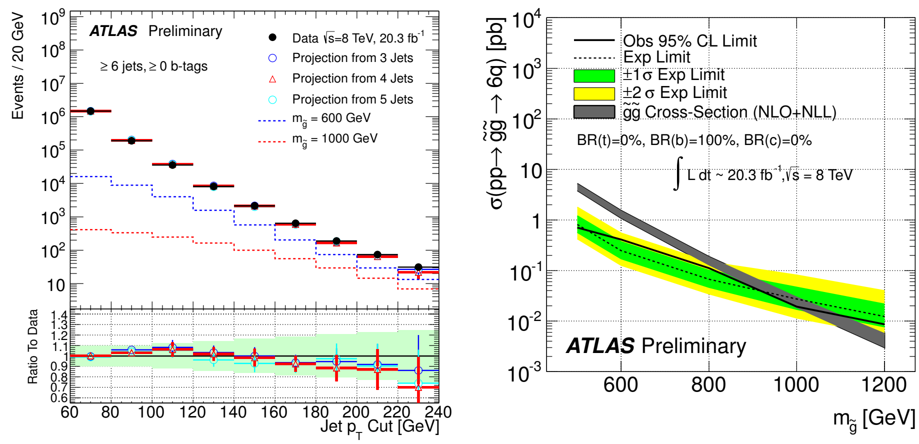

Fig. 7. (Left) The number of observed events with ≥6 jets is compared with two signal models, and with expectations that are determined by using Pythia to project the number of observed events from low-jet multiplicity control regions. In the ratio plots the green bands convey the background systematic uncertainties. (Right) Expected and observed cross-section limits for the 6-quark gluino model where every gluino decays into a b-quark in the final state [12].

interaction point. Such a search for the decay of a heavy particle, producing a multi-track vertex that contains a high p_T muon, at a distance between 0.4 cm to 18 cm from the pp interaction point has been carried out [13]. To reduce the background from hadronic interactions, the vertex is searched in a low density material region. The total background contribution is estimated to be very small (0.02±0.02). No candidate events are observed in the data and the results are translated into limits in the context of a RPV scenario as shown in Fig. 8. The limits are reported as a function of the neutralino lifetime and for a range of neutralino masses and velocities. Branching ratios of 50% and 100% for the decay chain from squarks to neutralinos to muon-plus-quarks are considered.

4. Conclusions

The ATLAS experiment has carried out extensive studies in the search for physics beyond the Standard Model. So far, no evidence for new physics has been found. The investigation of the 7 and 8 TeV data continues, while the data from the upcoming LHC Run 2 will greatly extend the discovery reach of many analyses presented here.

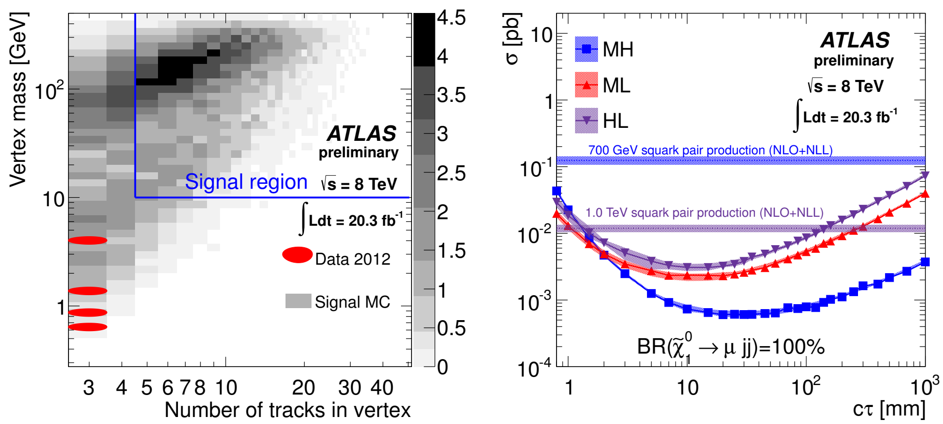

Fig. 8. (Left) Vertex mass vs track multiplicity for reconstructed displaced vertices in non-material regions, where all event, muon, and vertex selection requirements are satisfied. (Right) Upper limits at 95% CL on sigma vs neutralino lifetime for different combinations of squark and neutralino masses, based on the observation of zero events satisfying all criteria in a 20.3 fb^{-1} data sample, for the case where the branching ratio for the decay chain from squark to neutralino to muon-plus-jets is 100% [13].

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